REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 1997	Magazine

4. TITLE AND SUBTITLE
Gateway: Volume VIII, Number 1

5. FUNDING NUMBERS
SPO900-94-D-0001

6. AUTHOR(S)
Kim Vicente
Aaron Schopper
Stuart Card
Rueben L. Hann

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Human Systems IAC
2261 Monahan Way, Bldg. 196
WPAFB, OH 45433-7022

8. PERFORMING ORGANIZATION REPORT NUMBER
GWVIII1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Technical Information Cntr.
DTIC/AI
Cameron Station
Alexandria, VA 22304-6145

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.
Free to public by contacting the Human Systems IAC.
Free on internet at http://iac.dtic.mil/hsiac

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 Words)*

This issue contains articles on the following subjects: 1.Should an Interface Always Match the Operator's Mental Model; 2.Information Visualization and Information Foraging; 3.A Conversation with Stuart Card; 3.Aircraft Mishap Investigation: A Role for Human Factors Consultants

20010105 105

14. SUBJECT TERMS
Cognitive Compatibility Human-Computer Interface
Information Visualization Aircraft Mishap Investigation

15. NUMBER OF PAGES
16

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

VOLUME VIII: NUMBER 1 (1997)

CSERIAC GATEWAY

PUBLISHED BY THE CREW SYSTEM ERGONOMICS INFORMATION ANALYSIS CENTER

In this issue:

CSERIAC is a United States Department of Defense Information Analysis Center administered by the Defense Technical Information Center, Ft. Belvoir, VA, technically managed by the Armstrong Laboratory Human Engineering Division, Wright-Patterson Air Force Base, OH, and operated by the University of Dayton Research Institute, Dayton, OH.

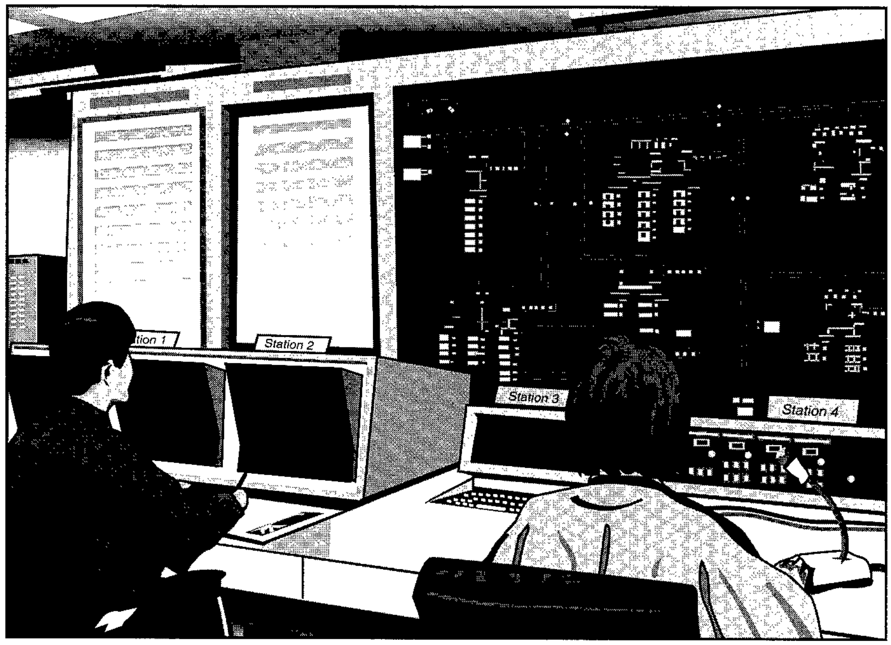


Figure 1. Different operators in a power plant control room may have different mental models of plant functioning, and none may faithfully capture how the plant actually works. Illustration by Ronald T. Acklin, University of Dayton.

Should an Interface Always Match the Operator's Mental Model?

Kim Vicente

Human factors professionals know that it is always important to design a human-computer interface to be compatible with the operator's mental model of the system to be controlled. Or is it? This article will critically examine the *cognitive compatibility principle* to determine if it is valid and useful for all types of application domains. In particular its usefulness will be evaluated for work domains that impose dynamic, objective, environmental constraints (e.g., the positions of other aircraft and the terrain in aviation, and the laws of physics governing a nuclear power plant) on the goal-directed behavior of human operators. Following Vicente (1990), these work domains will be referred to as *correspondence-driven.* This article will conclude that in these cases cognitive compatibility is impotent without first establishing *ecological compatibility.*

The Cognitive Compatability Principle

Limitations of Mental Models

In a review of advanced alarm and diagnostic systems for nuclear power plants, Kim (1994) provides a clear statement advocating the cognitive compatibility principle: "The comput-

Continued on page 2

erized systems for on-line management of plant anomalies must provide the operators with representations of plant functions that are compatible with their mental image of the plant, the so-called mental model or conceptual model" (p. 293). This may seem like a logical and defensible claim, but it overlooks an important factor. What if the operator's mental model is incomplete, or even worse, incorrect in the sense that it does not faithfully capture how the plant actually works? Given the human factors design inadequacies in existing control rooms, and the fact that the control room design can shape operators' mental models, one can hardly take it for granted that deficiencies in operators' mental models do not exist. How useful would it be, then, to design an interface that is consistent with an operator's mental model but that describes the plant in a way that is incorrect or incomplete? The answer to this question should be self-evident since the laws of physics are unforgiving.

For those who remain unconvinced, however, an anecdote from the nuclear industry should help to illustrate the limitations of the cognitive compatibility principle. One nuclear power plant vendor chose an exceptionally skilled operator to participate in the design of a new control room. This practice is consistent with existing theories of "participatory design" or "user-centered design," the goal being to get user input into the design process. This is a laudable goal and represents a distinct improvement over traditional design practices which essentially leave the user out of the design process. Nevertheless, the moral of this anecdote is that it is possible to take this user-centered approach too far. When the new control room design was shown to other operators, the designers quickly realized that the design process they had adopted was faulty. The first valuable lesson they learned was that other operators did not think of the plant in the same way as the exceptional operator who was part of the design team. In fact, no two operators seemed to have the same mental model of the plant. This finding caused the designers to reflect more deeply upon the relationship between operators' mental models and the engineering laws and principles governing plant behavior. This reflective exercise revealed another valuable lesson, namely that all of the operator's mental models were limited in the sense that they contained misconceptions, omissions, or both. As a result, the control room in question had to be redesigned to reflect better the way in which the plant actually worked. Needless to say, this was a costly and time-consuming process.

Functional Similarity and Mental Models

Some readers might think that this critique of cognitive compatibility is self-evident. If this is the case, then one would expect that all prominent human factors theories would have incorporated these considerations. To determine whether this is the case, let's examine briefly the well-known *proximity compatibility principle* (PCP) (Wickens & Carswell, 1995). In a nutshell, the PCP states that the perceptual characteristics of displays should be designed to be compatible with the cognitive processes used by operators to perform a particular task. For example, if operators use two sources of information to complete a task, then the display should somehow integrate these data for the operator. Conversely, if the operator focuses on a single source of information to complete a task, then that datum should be presented so that it is separate from other data.

It is clear from the applications chosen to evaluate the PCP (e.g., aviation, process control) that it is intended to be applied to correspondence-driven work domains. Nevertheless, Wickens and Carswell (1995) clearly advocate the cognitive compatibility principle. For example, in defining various forms of task proximity (which, according to PCP, dictate what type of displays should be designed), Wickens and Carswell (1995) discuss the concept of functional similarity, which they state "refers to the similarity of the units or objects being measured, *as represented in the operator's semantic space*" (p. 476, emphasis added). They then go on to state that "functional similarity could be derived from multidimensional scaling techniques eliciting the structure of the *operator's* semantic space or mental model of the displayed system" (p. 476, emphasis added).

These recommendations made by the PCP are subject to the critique already presented above. Focusing on cognitive compatibility overlooks the fact that the operator's mental model may be incorrect or incomplete. Furthermore, basing a display on a "buggy" mental model can be a costly mistake, as the anecdote from the nuclear industry made clear.

Inadequacy of the Information Processing Approach

The cognitive compatibility principle focuses so much on the characteristics of the human operator that it virtually ignores the characteristics of the system being controlled. This can be a significant problem in correspondence-driven work domains that impose dynamic, objective, environmental constraints on productive operator behavior.

What might be the cause of this oversight? The reason seems to be that the cognitive compatibility principle is based on an information-processing approach to human factors (e.g., Wickens, 1992). This approach begins with, and devotes most of its theoretical energy to, analyzing and describing human characteristics. As a result, the information processing approach tends to underemphasize the design relevance of the environment in which behavior takes place. This can be seen by contrasting the traditional information-processing

approach with a more recent alternative, the ecological approach to human factors (Flach, Hancock, Caird, & Vicente, 1995; Hancock, Flach, Caird, & Vicente, 1995).

The Ecological Approach

The ecological approach to human factors is based on the concepts developed within ecological psychology (Brunswik, 1956; Gibson, 1979). Interestingly, this approach has strong ties with systems engineering as well (cf. Meister, 1989). More important for the purposes of this article is the fact that the ecological approach has several characteristics that distinguish it from traditional approaches to human factors based on information processing psychology (Vicente, 1995). Whereas more traditional approaches (e.g., Wickens, 1992) tend to put a great deal of emphasis on analyzing human characteristics, the ecological approach (e.g., Rasmussen, Pejtersen, & Goodstein, 1994) puts much more emphasis on analyzing the interaction between people and their environment. It is important to note that the term "environment" here is used in a very broad sense. Depending on the domain of application and the question of interest, the environment can be the physical properties of a workplace (e.g., lighting, heat, humidity), the demands of the tasks that people are required to perform (e.g., landing vs. take-off in aviation), the structural characteristics of the work domain people are interacting with (e.g., flexible manufacturing system, nuclear power plant), the values and organizational structure of the company they work in (e.g., safety culture, matrix organization, respectively), and even the nature of the climate that governs the particular industry of which people are a part (e.g., how tightly regulated the industry is, how many companies are competing for the same market). One of the fundamental commitments of the ecological approach is that it is not possible to understand human behavior without simultaneously understanding the environment in which people are acting.

Consequently, the ecological approach demands that we explicitly analyze the constraints that the environment imposes on behavior (in addition to investigating the characteristics of people). Even more strongly, however, the ecological approach claims that it is important to *begin* by analyzing the environment before analyzing what people are doing, or how they are doing it, or what they know. This provides a strong contrast to the information-processing approach to human factors, which focuses primarily on the individual. This difference can be observed in the familiar flow diagrams illustrating the various stages of human information processing (e.g., sensation, perception, attention, working memory, long-term memory, decision making, problem solving, planning, motor control). Not only does the environment in which behavior takes place not play a central role in these diagrams, but in many cases, the environment is not even explicitly represented (except perhaps in a very spartan manner by a feedback loop from motor control to sensation).

Relevance to Interface Design

What does the ecological approach have to say about how interfaces should be designed for correspondence-driven work domains? Instead of focusing exclusively on cognitive compatibility, this approach suggests an *ecological compatibility principle*: the design process should begin by ensuring that the content and structure of the interface are compatible with the constraints that actually govern the process to be controlled. In doing so, the goal is to ensure that operators will acquire a *veridical* mental model of the work domain, so that their understanding corresponds, as closely as possible, to the actual behavior of the system. This is not to say that psychological considerations are not important. Whereas the *content* and *structure* of the interface are dictated by ecological considerations, the *form* of the interface should be designed to be cognitively compatible with the properties of human cognition, action, and perception.

One can generalize this argument to any application domain where there is an external reality–outside of the person and the computer–that imposes dynamic, goal-relevant constraints on meaningful behavior (Vicente, 1990). For these correspondence-driven work domains, operators' mental models should correspond with this external reality and thus the interface should be based on the ecological compatibility principle. There are many examples of such domains aside from the prototypical example of nuclear power. To take but one, in aviation it is important that pilots' mental models of how the aircraft functions, of geometric constraints in 3-D space, and of the flight management system (FMS) be accurate. Thus interfaces displaying the status of aircraft systems, air traffic, and the FMS should be based on the constraints that describe how these entities *actually* work, not on how pilots *might think* they work. Adopting the cognitive compatibility principle would support the operator's mental model, but would eventually lead to a rude awakening when the pilot's assessment of a situation does not correspond to what is actually going on.

Potential Counterarguments

To avoid any misconceptions, it is important to address head-on several potential objections to this critique. First, it could be argued that I have presented a straw man. After all, how could anyone possibly advocate designing an interface based on a grossly incorrect operator mental model? The only way to determine if I have misrepresented others' views is to look closely at the words they use. It is certainly true that neither of the papers cited earlier in the discussion

Continued on page 4

of the cognitive compatability principle directly states that interfaces should be designed according to system models that are incorrect or incomplete. However, it does not follow that those papers reflect an appreciation for the importance of the ecological compatibility principle. The fact of the matter is that Wickens and Carswell (1995), for instance, never explicitly state that a display should be designed to be compatible with the way the system actually works. Moreover, the words that they do use (see above) indirectly conflict with such an assertion.

Second, it could be argued that operators' mental models do not have to be exactly accurate. As long as they are "close enough," then performance may not suffer. This may be true for the set of situations that operators encounter frequently and to which they have adapted. However, accident analyses have repeatedly shown that when unfamiliar, abnormal events that are outside of operators' adaptation boundaries occur, the divergence between operators' mental models and the actual behavior of the system becomes practically significant and greatly jeopardizes system safety (Rasmussen, 1986). Thus "close enough" may be good enough most of the time, but in systems where the consequences of error have enormous financial, safety, and environmental implications, a more cautious and thorough approach to interface design is required.

Third, one could argue that there are several different correct mental models for any system with objective characteristics. This is absolutely correct, but it does not invalidate the critique of cognitive compatibility presented above. After all, just because there are several equally faithful mental models does not mean that designers can assume that operators have one of those models. It is always important to make sure that the system model serving as the basis for interface design captures the way in which the system actually works.

This latter point opens the way for integrating ecological compatibility and cognitive compatibility. It should be clear by now that cognitive compatibility is of little use unless ecological compatibility has already been established. That is, making an interface compatible with an operator's mental model will not do much good if that model does not correspond with the way the system actually works. However, given that ecological compatibility has been ensured, cognitive compatibility provides a useful way of closing the remaining degrees of freedom in interface design. Bringing together these two principles in this order is productive because it ensures that interfaces will present operators with the information they need to develop accurate mental models in a form that is compatible with existing knowledge of human cognition.

Conclusion

Designing a human-computer interface so as to be compatible with the operator's mental model of the system to be controlled is inappropriate for applications domains where there is an objective reality imposing dynamic, goal-relevant constraints on meaningful behavior. In these cases, it is more appropriate to begin the design process by creating an interface that is compatible with the actual constraints of the environment. Only then will cognitive compatibility have any potency as a design principle. This observation follows directly from the ecological approach and shows the limitations of the more traditional information-processing approach to human factors. Moreover, this illustrates that the ecological approach can make significant contributions to our discipline that build upon those of more traditional approaches. ●

Acknowledgments

The writing of this article was sponsored by grants from the Natural Sciences and Engineering Research Council of Canada. I would like to thank Jeff Landis for his kind invitation, Cathy Burns for suggesting the theme for the article, and an anonymous reviewer for vigorous, yet constructive, criticisms.

References

Brunswik, E. (1956). *Perception and the representative design of experiments* (2nd ed.). Berkeley, CA: University of California Press.

Flach, J., Hancock, P., Caird, J., & Vicente, K. J. (1995). *Global perspectives on the ecology of human-machine systems.* Hillsdale, NJ: Erlbaum.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston, MA: Houghton-Mifflin.

Hancock, P., Flach, J., Caird, J., & Vicente, K. J. (1995). *Local applications of the ecological approach to human-machine systems.* Hillsdale, NJ: Erlbaum

Kim, I. S. (1994). Computerized systems for on-line management failures: A state-of-the-art discussion of alarm systems and diagnostic systems applied in the nuclear industry. *Reliability Engineering and System Safety, 44*, 279-295.

Meister, D. (1989). *Conceptual aspects of human factors.* Baltimore, MD: Johns Hopkins University Press.

Rasmussen, J. (1986). *Information processing and human-machine interaction: An approach to cognitive engineering.* Amsterdam: North-Holland.

Rasmussen, J., Pejtersen, A. M., & Goodstein, L. P. (1994). *Cognitive systems engineering.* New York: Wiley.

Vicente, K. J. (1990). Coherence- and correspondence-driven work domains: Implications for systems

design. *Behaviour and Information Technology, 9,* 493-502.

Vicente, K. J. (1995). A few implications of an ecological approach to human factors. In J. Flach, P. Hancock, J. Caird, & K. J. Vicente (Eds.), *Global Perspectives on the Ecology of Human-Machine Systems,* (pp. 54-67). Hillsdale, NJ: Erlbaum.

Wickens, C. D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: Harper-Collins.

Wickens, C. D., & Carswell, M. (1995). The proximity compatibility principle: Its psychological foundation and relevance to display design. *Human Factors, 37,* 473-494.

Kim J. Vicente, Ph.D., is an Associate Professor of Mechanical & Industrial Engineering and of Biomedical Engineering, and Director of the Cognitive Engineering Laboratory, University of Toronto, Ontario, Canada. Email: benfica@mie.utoronto.ca

GATEWAY

August 18-20, 1997
Madison, WI, USA
Using Ergonomic Fundamentals to Analyze and Design Jobs, Work Methods and Workstations short course. Sponsored by the College of Engineering, University of Wisconsin-Madison. Contact Engineering Registration, The Wisconsin Center, 702 Langdon Street, Madison, WI 53706. Tel: 800-462-0876 or 608-262-1299, Fax: 800-442-4214 or 608-265-3448, Email: custserv@epd.engr.wisc.edu, WWW: http://epdwww.engr.wisc.edu/

August 20-22, 1997
Madison, WI, USA
Advanced Ergonomics Application Workshop. Sponsored by the College of Engineering, University of Wisconsin-Madison. Contact Engineering Registration, The Wisconsin Center, 702 Langdon Street, Madison, WI 53706. Tel: 800-462-0876 or 608-262-1299, Fax: 800-442-4214 or 608-265-3448, Email: custserv@epd.engr.wisc.edu, WWW: http://epdwww.engr.wisc.edu/

August 24-29, 1997
San Francisco, CA, USA
HCI International '97. 7th International Conference on Human-Computer Interaction. Contact Dr. Gavriel Salvendy, General Chair, or Kim Gilbert, Conference Administrator, School of Industrial Engineering, Purdue University, 1287 Grissom Hall, West Lafayette, IN 47907-1287. Tel: 317-494-5426, Fax: 317-494-0874, Email: salvendy@ecn.purdue.edu, WWW: http://palette.ecn.purdue.edu/~salvendy/hci97/

September 8-10, 1997
York, United Kingdom
16th Annual Conference on Computer Safety, Reliability, and Security. Contact Ginny Wilson, SAFECOMP'97, Department of Computer Science, The University of York, York Y01 5DD, United Kingdom. Tel: +44-1904-432782, Fax: +44-1904-432708, Email: safecomp-97@minister.york.ac.uk, WWW: http://www.cs.york.ac.uk/safecomp-97

September 14-17, 1997
Marseilles, France
Seventh International Conference on Vision in Vehicles. Contact VIV7, Applied Vision Research Unit,University of Derby,Mickleover, Derby DE3 5GX, United Kingdom. Tel & Fax: +44-1332-622287, Email: avru@derby.ac.uk, WWW: http://www-hcs.derby.ac.uk/avru/

September 15-20, 1997
Stockholm, Sweden
25th International Congress on Occupational Health (ICOH). Contact ICOH-Congress, National Institute of Occupational Health, S-171 84 Solna, Sweden. Fax: +46-882-05-56.

September 22-26, 1997
Albuquerque, NM, USA
41st Annual Meeting of the Human Factors and Ergonomics Society, "Ancient Wisdom–Future Technology." Contact the Human Factors and Ergonomics Society, PO Box 1369, Santa Monica, CA 90406-1369, USA. Tel: 310-394-1811, Fax: 310-394-2410, Email: hfeshq@aol.com, WWW: http://hfes.org

October 1-3, 1997
Galway, Ireland
International Conference on Revisiting the "Allocation of Function" Issue: New Perspectives. Contact: Edna F. Fallon, Centre for Occupational Health and Safety Studies, Department of Industrial Engineering, University College, Galway, Ireland. Tel: +353-91-52524411, Ext 2770 or 2754; Fax: +353-91-750524; Email: enda.fallon@ucg.ie; WWW: http://indeng.ucg.ie/allfn97

October 7-9, 1997
Yellow Springs, OH, USA
A short course in Anthropometry emphasizing hands-on training in anthropometric measurement and providing background lecture material. Contact Anthropometry Research Project, Inc., PO Box 307, Yellow Springs, OH 45387. Tel: 937-767-7226, Fax: 937-767-9350, Email: bbradt@aol.com

November 3-6, 1997
Orlando, FL, USA
20th Anniversary and 39th Biennial Meeting of the US Department of Defense Human Factors Engineering Technical Advisory Group (DoD HFE TAG). Contact Sheryl Cosing, 10822 Crippen Vale Court, Reston, VA 20194. Tel: 703-925-9791, Fax: 703-925-9644, Email: sherylynn@aol.com *The meeting is open to all government personnel and others by specific invitation.*

November 6-8, 1997
Kuala Lumpur, Malaysia
Association of Southeast Asian Nations (ASEAN) Ergonomics 1997 - 5th Southeast Asian Ergonomics Society (SEAES) Conference. Contact Dr. Halimahtun Mohd Khalid, Centre for Applied Learning and Multimedia, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia. Tel: +6082-672311, Fax: +6082-672312, Email: hali@calm.unimas.my, WWW: http://www.unimas.my

November 17-19, 1997
Chicago, IL, USA
6th Annual National Workers' Compensation and Disability Conference and Exhibit. Contact LRP Publications Conference Division, 1555 King Street, Suite 200, Alexandria, VA 22314. Tel: 800-727-1227 or 703-684-0510, Fax: 703-739-0489.

March 22-24, 1998
Dayton, OH, USA
Fourth Symposium on Human Interaction with Complex Systems (HICS). Contact Dr. John M. Flach, Psychology Department, Wright State University, Dayton, OH 45435. Tel: 937-873-2391, Fax: 937-873-3347, Email: jflach@desire.wright.edu *Papers (≤15 double-spaced pages) are due November 1, 1997. Posters (2-page abstract) are due January 15, 1998. Proposals for special sessions and panels on relevant topics are due November 1, 1997.*

April 1-3, 1998
Cirencester, Gloucestershire, UK
1998 Annual Conference of the Ergonomics Society. Contact Conference Manager, The Ergonomics Society, Devonshire House, Devonshire Square, Loughborough, Leics LE11 3DW, United Kingdom. Tel & Fax: +44-1509-234904, WWW: http://www.ergonomics.org.uk/ *Abstracts of papers are due September 26, 1997, and camera-ready papers are due January 2, 1998.*

May 17-20, 1998
Amsterdam, The Netherlands
4th World Conference on Injury Prevention and Control: Building Partnerships for Safety Promotion and Accident Prevention. Contact Conference Secretariat, Injury Prevention & Control, PO Box 1558, 6501 BN Nijmegen, The Netherlands. Tel: +31-24-323-44-71, Fax: +31-24-360-11-59, WWW: http://www.consafe.nl/conference/

Notices for the calendar should be sent at least four months in advance to:
CSERIAC Gateway Calendar, AL/CFH/CSERIAC Bldg 248, 2255 H Street, Wright-Patterson AFB OH 45433-7022

The CSERIAC Interface
In Search of a Functional Relationship

Aaron "Ron" Schopper

You and your spouse or "significant other" have one; the arrangement of the furniture in your home or apartment likely reflects one; but can the human factors profession define one? "Functional relationship," that is.

We've been working on a forthcoming state-of-the-art report (SOAR) pertaining to computational models of human performance as relates to the layout of controls and displays. In reading the materials associated with that topic, the terms "functionally related" and "functional relationships" were encountered with some frequency. Wanting to pin this concept down, I thought it might help if we included the definition for same. And wanting to use a definition that reflected the human factors/ergonomics profession, I first decided to examine the mainstream human factors references (i.e., popular HF texts and handbooks) to determine how they defined this concept. Accordingly, I searched the subject index of each that I could find on the library shelves and, to my surprise, the term "functional relationship" did not appear in any of them. I then examined James H. Stramler's *The Dictionary for Human Factors/Ergonomics* (Ann Arbor: CRC Press, 1993). Therein I found definitions for 17 different "functional xxxs" (ranging from "Functional Analysis Systems Technique [FAST]" and "functional anatomy" [p. 125] through "functional leg length" [p. 126] to "functional vibration" [p. 126]), but none for "functional relationship." And lastly, I consulted the DoD's principal reference to the topic at hand: *MIL-HDBK 1908, Department of Defense Handbook for Definitions of Human Factors Terms* (December 11, 1995) and obtained the now-anticipated result: no listing. Given the consistency of these negative findings, one is tempted to ask if "functional relationship" is a viable human factors concept.

Returning to the specific human factors topic of control and display layout, other frequently cited approaches appear to be less ambiguous and more readily differentiable, e.g., frequency-of-use, sequence-of-use, importance. Each seems reasonably intuitive (albeit mathematical formulae abound for some), and the general process for deriving the information needed can be readily appreciated.

However, such was not the case for *functional relationship*. In some instances it seemed to be used in lieu of another term that would have been more informative (e.g., sequence of use). In others, it appeared to have been used as the equivalent of some unstated but potentially investigable set of relationships–a sort of umbrella term or shorthand for a yet-to-be-done set of multivariate analyses.

We (within the human factors community) all know what a functional relationship is. I verified that with my colleagues in the office before I pursued the somewhat more "academic" approach of looking through the better-known human factors references. Each individual I spoke with believed that he or she knew what a functional relationship was, but just how to articulate same seemed problematic.

Perhaps I've missed something, but *functional relationship* seems to be useful only as an umbrella concept whose use would be acceptable (otherwise unexplained) when one addresses lay groups and wishes only to assert that an underlying rationale exists for the layout of a particular set of controls and/or displays-but not wanting to describe same in more precise, technical terms. However, without undertaking additional investigation or analyses (and reporting same), I don't believe that it contributes to our knowledge-or advances our cause-when used in an explanatory context within our professional communications and reports. (And I believe much the same regarding the broad, unamplified use of the concept *importance,* and several others that have crept into our human factors vocabularies-but perhaps another day.)

Any reaction? I admit my "research" was very limited, and I'm sure my opinions are not shared by all. Moreover, I acknowledge that there is considerable "straw" in my discussion-but straw men can be interesting if for no other reason than to discover the intellectual match needed to set them ablaze and cause their demise. Come on! Jump in! Provide clarification or offer a different perspective or opinion. Give us an alternative definition (e.g., your own or one you were able to find in a journal article or other, more focused source). The most interesting, insightful, and/or amusing responses will be reported and acknowledged. ●

Aaron "Ron" Schopper, Ph.D., is the Chief Scientific and Technical Advisor for the CSERIAC Program Office.

Dear CSERIAC...

To show the diversity of support that CSERIAC provides, this column contains a sampling of some of the more interesting questions asked of CSERIAC. In response to these questions, CSERIAC conducts literature and reference searches, and, in some cases, consults with subject area experts. These questions were compiled by Debra Urzi, Human Factors Engineer. If you would like to comment on any of these questions or issues related to them, please write to "Dear CSERIAC" at the address found on the back cover of *Gateway.*

- A human factors consulting firm in California requested a Review and Analysis to explore the basic human factors data and information available that could influence early decisions concerning the driver's role in the automated highway systems of the future.

- A representative of a British company contacted CSERIAC requesting information on the measurement of situation awareness in virtual environments, particularly, the use of the measuring tool SAGAT.

- CSERIAC received an inquiry regarding the readability of black text on white and colored background in both computer and hardcopy applications.

- A member of the US Naval Submarine Medical Research Laboratory requested information about the effects of automation on humans.

- The US Air Force Fitness Program Office asked CSERIAC to investigate, analyze, and document information on the standards of assessing aerobic performance.

- CSERIAC was asked by US Army Simulation, Training and Instrumentation Command (STRICOM) to provide information regarding the dynamics of designing training systems that target the type of materials to be learned as opposed to the "one-size-fits-all" approach.

- An Atlanta, Georgia human factors consulting firm asked CSERIAC for information regarding different strategies for navigating through moving map displays.

- A student at the University of Dayton requested information that could be used in testing and evaluating a workstation for those with disabilities.

- Information pertaining to eye dimensions and facial anthropometry for Latin and Native Americans was requested from CSERIAC.

- A representative of a major automobile manufacturer near Dayton, Ohio contacted CSERIAC to determine the human factor issues that should be considered regarding job rotation frequency.

- A designer from Cincinnati, Ohio, requested information to be used to determine a way of calculating an appropriate movement time for a new safety feature of a pneumatic nailer.

- CSERIAC was asked by a US shoe manufacturer to research any possible benefits to wearers of cushioned work shoes.

Armstrong Laboratory Human Engineering Division Colloquium Series

Information Visualization and Information Foraging

Stuart Card

Editor's note: Following is a synopsis of a presentation by Dr. Stuart Card, Xerox Palo Alto Research Center, CA, as the third speaker in the 1996 Armstrong Laboratory Human Engineering Division Colloquium Series: Human-Technology Integration. This synopsis was prepared by Michael Reynolds, Senior Human Factors Engineer, CSERIAC Program Office. JAL

Dr. Card defined "large-scale cognition" as "the application of intelligence to tasks that have lots of bits of information … in particular, to interfaces that contain hundreds of bits instead of the tens of bits typically presented in a Windows graphical user interface."

To illustrate the large-scale cognition concept, Card spoke of the explosion in information, specifically in terms of the number of available scientific journals. While the number of journals has been increasing by a factor of ten every fifty years, human capacity has remained constant. Vanevar Bush noted as early as 1945 that "the investigator is staggered by the findings and conclusions of thousands of other workers—conclusions which he cannot find time to grasp, much less to remember, as they would appear." Bush developed the Memex desk (see Fig. 1) that, while not a commercial success, demonstrated his vision of using technology to make it possible to comprehend and deal with huge amounts of information. The Memex desk spawned numerous research projects that have led to advances in computer graphics, hypertext, and graphical user interfaces.

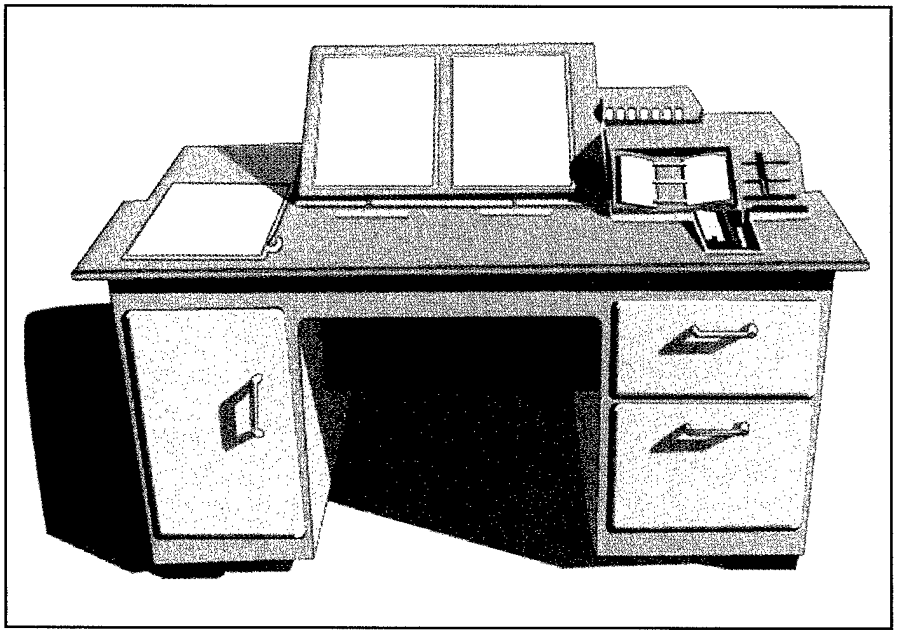


Figure 1. The Memex desk. Illustration by Ronald T. Acklin, University of Dayton.

The evolution of information-processing capability begins with writing, and progresses through Codex, printing, typewriter, copier, fax, personal computer, visual computing, and the world-wide web. These inventions are attempts to deal with the growth of information. Humans are "informavores" in Card's words; they use large amounts of information to generate some resulting output. The critical resource therefore is time. Herbert Simon has said that "information consumes the attention of its recipients and hence a wealth of information creates a poverty of attention and a need to allocate efficiently among the overabundance of information sources that might consume it."

Thus while information is rapidly increasing, the goal is not to create or unleash more information, but to gain more insight from the information per unit time. Card described the process of gaining information insight efficiently as a "knowledge crystallization task" (see Fig. 2) and broke this task down into three subcomponents: information foraging, sensemaking, and knowledge product (a decision, action, or document).

Large complex cognitive tasks have to be accomplished "outside the head" as the human quickly runs out of working memory. What is needed is a better coupling between the human and the information. To accomplish that, the next generation of user interfaces (UI) will have several advanced characteristics. For example, the UI will be perceptually loaded to reduce cognitive load and have a richer perceptual vocabulary. The UI will allow for human time-layered interaction, that is, a higher quality of display wherein information transfer rates are matched to the human's abilities.

Card identified four ways to enhance the complex cognition task. The first is through information space

Continued on page 10

visualization methods, for example three-dimensional mapping techniques, cone trees, and hyperbolic browsers.

Second, workspace visualization methods can be developed, workspace being defined as a special environment in which the cost structure of the needed materials is tuned to the requirements of the work process using them. The workspace visualization method is based on the locality of reference principle, that is, the probability of using a piece of information determines it locality. An information workspace is modeled by a cost-of-knowledge characteristic function; a system that allows more information in a given period of time is, of course, a better system.

The third enhancement method comprises sensemaking visualization tools. These tools allow the user to manipulate the retrieved information to understand the sub-pieces more rapidly (for example, through more efficient zooming). Tools can be provided to allow one to swap between general context views and focused views.

Fourth are document visualization tools that allow the user to vary the level of detail and create multiple threads. A Xerox concept, which employs many of these four enhancement techniques, presents an office workspace analogy (see Fig. 3) that shows a bookshelf, books, pages of the book, and a desk. The system employs a gesture navigation system that allows the user to turn pages of a displayed book as well as view many pages simultaneously. A web book/forager example was presented which uses a book analogy for web pages. Pages can be flipped through, multiple pages viewed simultaneously, and individual pages can be scrolled if desired.

In summary, as information is increasing, the goal is not to acquire more information but to gain more insight in the available time. Complex cognition is enhanced by manipulable displays, especially computers through information space visualization, workspace visualization, sensemaking tools, and document visualization. Card touched briefly on two other theories being examined in the context of the complex cognition task, information foraging theory and sensemaking theory, as they are being applied to the work at Xerox.

Finally, Card answered several questions in areas such as marketplace applications of his work and provided more specific explanations of concepts. ●

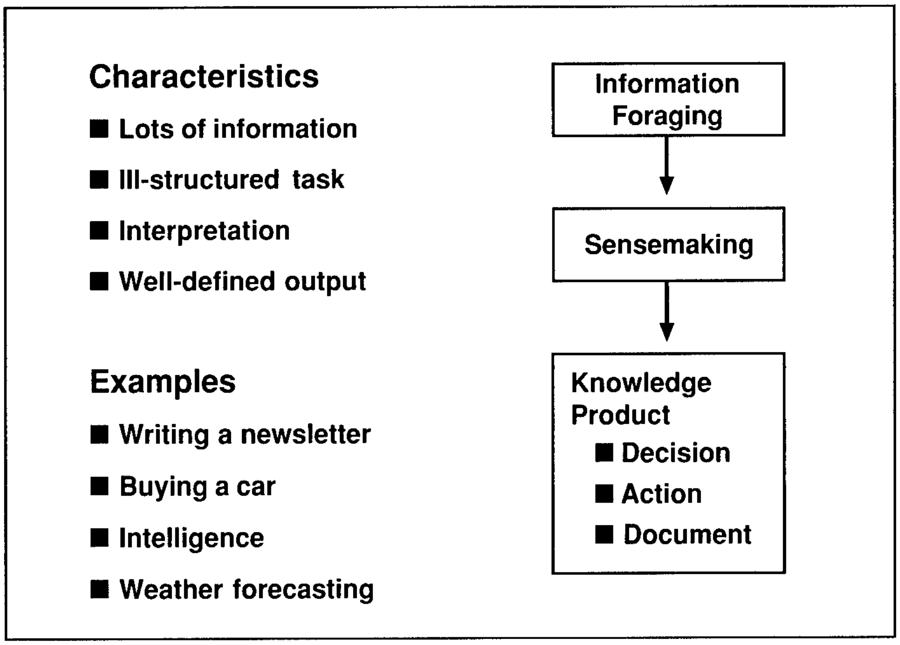


Figure 2. The knowledge crystallization task.

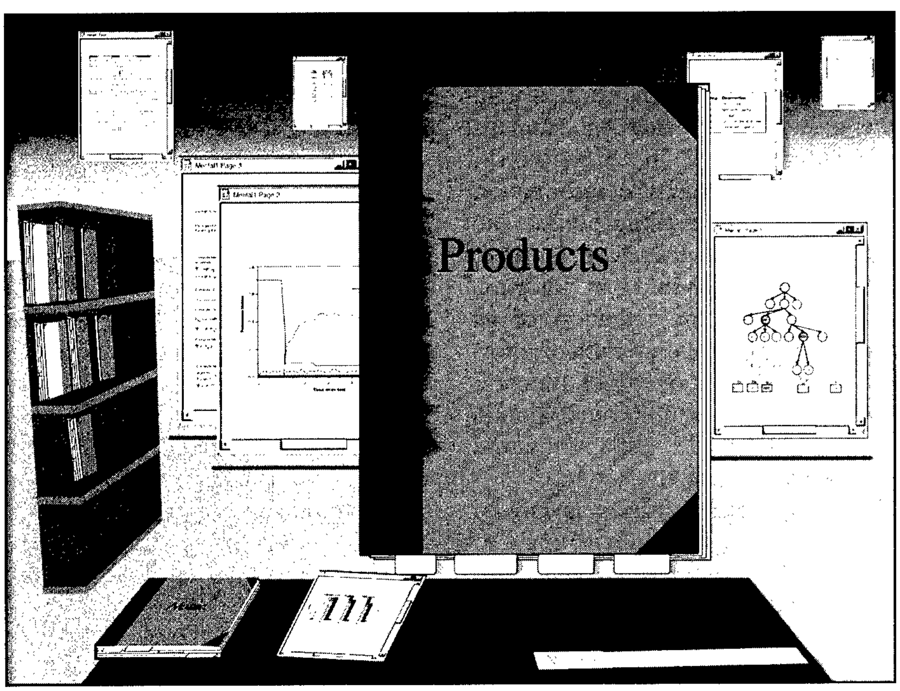


Figure 3. Document visualization tools developed by Xerox. Illustration by Ronald A. Acklin, University of Dayton.

Armstrong Laboratory Human Engineering Division Colloquium Series
A Conversation with Stuart Card

Rueben L. Hann

Editor's note: The following is an edited transcript of a conversation with Dr. Stuart Card, Xerox Palo Alto Research Center (see Fig. 1). He spoke on "Information Visualization and Information Foraging" as the third speaker in the 1996 Armstrong Laboratory Human Engineering Division Colloquium Series: Human-Technology Integration. The interviewer was Dr. Lew Hann, former CSERIAC COTR. JAL

CSERIAC: I see your initial training was in physics. How did you get involved in psychological research?

Dr. Card: Well, while I was an undergraduate, Herb Simon came to our campus, and I became quite interested in the kind of things he was talking about—things which were sort of like artificial intelligence. So I went to Carnegie-Mellon to study with him and Alan Newell as part of the Systems and Communications Sciences program; it didn't seem to matter which part of it you were in. Then, as soon as I got there, the program terminated. So I essentially invented my own program of study.

Tom Moran and I later went back to Carnegie-Mellon to try to set up an applied psychological science program—one where you could do practical things, where you could use psychology in the same way you use chemistry and physics. You would help design products, apply for patents, and such.

CSERIAC: You are in an unusual situation, doing basic research within a corporate structure. Do you find this to be an advantage?

Dr. Card: Yes, I always wanted to do basic science on the one hand, but on the other hand I wanted to couple it to an actual application. I believe that doing just basic science without having an applied product come out of it is not enough. The application of the science is part of the proof of whether the concept is good enough. Just publishing the results of the basic research is not a strong enough test.

CSERIAC: I heard you use the expression "augmented reality" earlier today. How is this different from "virtual reality?"

Dr. Card: Work stations and computers today are delicately poised between two different kinds of realities—physical reality on one hand, and electronic reality on the other—that is, what is outside the machine and what is inside. Moving between these two realities is not very easy. There are three ways of fixing that. One way is to go off into virtual reality. So you get rid of physical reality entirely. You put things on people's eyes and every other sensory input possible, so there is as little "leakage" of the real world as possible. This creates the homogeneous world you want.

Another way to do it is to use

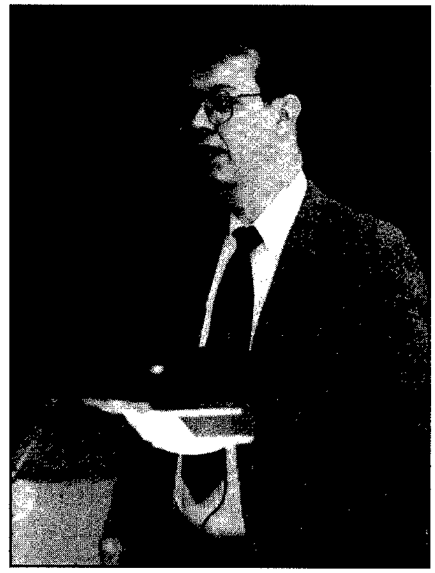


Figure 1. Stuart Card, Xerox Palo Alto Research Center, CA.

"embedded virtual reality," or "ubiquitous computing" where the computation is embedded. So, you never see a computer; the computer is embedded in the physical objects. The result once again is a homogeneous world.

There is an interesting third possibility, using "augmented reality." Here things are partly in both worlds. An example is the use of a "cave," where virtual reality is projected on screens all around you, so it seems like you are in the space. But on the other hand, you can see your pencil in front of your eyes, you can talk to other people, you can take notes. So you have a part of the physical reality also. There are about a dozen different ways to create augmented realities.

I believe that doing just basic science without having an applied product come out of it is not enough. The application of the science is part of the proof of whether the concept is good enough. Just publishing the results of the basic research is not a strong enough test.

Continued on page 12

Augmented realities have the advantage that you don't have to spend your whole working day with goggles on. I don't think I would like that. However, for specialized environments like working in space, where you need to have everything in the helmet, where you want to do a particular data analysis task, then I could see the advantage of a pure virtual reality approach.

CSERIAC: I know you were involved in the commercial development of the mouse as an input and control device. After all these years, it still shows no evidence of being replaced by another apparatus, even though many alternatives have been developed. The mouse is not dead.

Dr. Card: Certainly not. I did the original human factors study for the mouse. Xerox management was very reluctant to introduce it commercially. We did the usual human factors empirical studies to show the viability of the mouse, but the thing that won them over was the use of theory to explain why the performance was like it was.

We discovered the performance for the mouse was described by Fitts Law. Not only that, but the slope of the curve was roughly the same as that of the unaided hand. So that meant that the limitations of the mouse were not in the mouse, but in the eye-hand coordination system of the human. And that meant, if you put out the device on the market, somebody was not going to come along and just do a better device six months later and knock you out of the market. It meant that the mouse probably had staying power. Well, it turns out that it's true. It came out in 1983 and here it is still in use 14 years later.

CSERIAC: And that's in spite of all the alternative devices offered over the years.

Dr. Card: Yes, and the variations are not as good as the mouse in terms of actual performance. This is an example of something built on the theory established here [at the Armstrong Laboratory] in 1954. Because that theory existed, when we were looking at a particular device, we could understand its performance characteristics. We could use the theory to characterize the device in a way that is much more possible than with simple empirical studies.

There is a theme here. That is, one of the limitations of empirical studies in human factors—where you compare System A to System B—is that if you don't understand *why* you got that difference, then you really don't understand much, because if you change the context, you may get a different answer. However, if you have some sort of theory that says why you got that difference, then you have more confidence that you understand where that difference comes from. Now you can move that with more assurance to some other context, and you can make projections which go further. We could then use the theory to do very rapid evaluations. All we had to do was estimate the parameters of the Fitts Law slope. We discovered, for example, that the electronic circuitry of the first system Xerox was preparing to market wasn't adequate at the peak velocities of the mouse. Nobody knew what these peak velocities were, but we could calculate it from the theory. So we made them go back and put in a more expensive circuit, because we could predict what the limitations were going to be. Incidentally, we did this over lunch; we did not launch a six-month study. We were able to think it through by using the theory which was the basis of human performance in this task. ●

Aircraft Mishap Investigation: A Role for Human Factors Consultants

Maj Raymond E. King

When is an accident not an "accident?" When an aircraft crash or other misadventure is investigated to prevent reoccurrence, rather than to assign accountability or responsibility, it is termed a "mishap." If a cause can be identified, then steps toward future prevention of a similar situation can be taken. The chart below (see Fig. 1) shows a decreasing, but still significant, number of aircraft mishaps which underlies the importance of better understanding the causes of mishaps.

The Air Force promptly, but carefully, investigates and catalogs all incidents that cause damage to flying assets or injury to persons. The most serious are termed Class A mishaps and involve a fatality or loss of an aircraft or damage of at least one million dollars, and they always result in convening a Safety Investigation Board (SIB). The SIB is typically assembled from individuals within the mishap major command (MAJCOM), but from a different base than that of the mishap crew and aircraft, who meet at the Air Force base closest to the mishap cite. Less serious mishaps also receive scrutiny, but on a more local level.

To ensure maximum cooperation, privilege, or the ability to give anonymous testimony, is granted to witnesses so that problems or other concerns may be reported without fear of career loss or legal repercussions. An SIB differs from an Accident Investigation Board, which is conducted for administrative purposes–assigning accountability or responsibility. Information gleaned by the Accident Investigation Board can be used for legal purposes; witnesses are sworn and are not granted privilege. Most information gleaned during the SIB cannot be used by the Accident Investigation Board.

While the MAJCOM owning the mishap aircraft conducts the investigation, the Air Force Safety Center, headquartered at Kirtland Air Force Base, NM, provides guidance and consultation. Often a human factors consultant, perhaps from outside the mishap MAJCOM, must be quickly identified and put to work to determine why a mishap occurred and how to avoid a future similar event (see Fig. 2).

Human factors are responsible for approximately two thirds of all USAF mishaps, including incidents where a human did not initiate the problem, but also did not intervene to change the course of events. Moreover, "human" is not synonymous with "pilot" or even aircrew member. We need to look at the contribution of maintenance, aircraft design, training, procedures, air traffic control, and the culture of the flying squadron. Does the unit value completion of the mission regardless of the sacrifice involved? Or does the unit stress safety first, to the point of frequently failing to complete the mission on time? Most flying organizations will, of course, fall somewhere between these two extremes.

While most Air Force aircraft mishaps involve some degree of human error in the chain of events leading to the mishaps, human factors

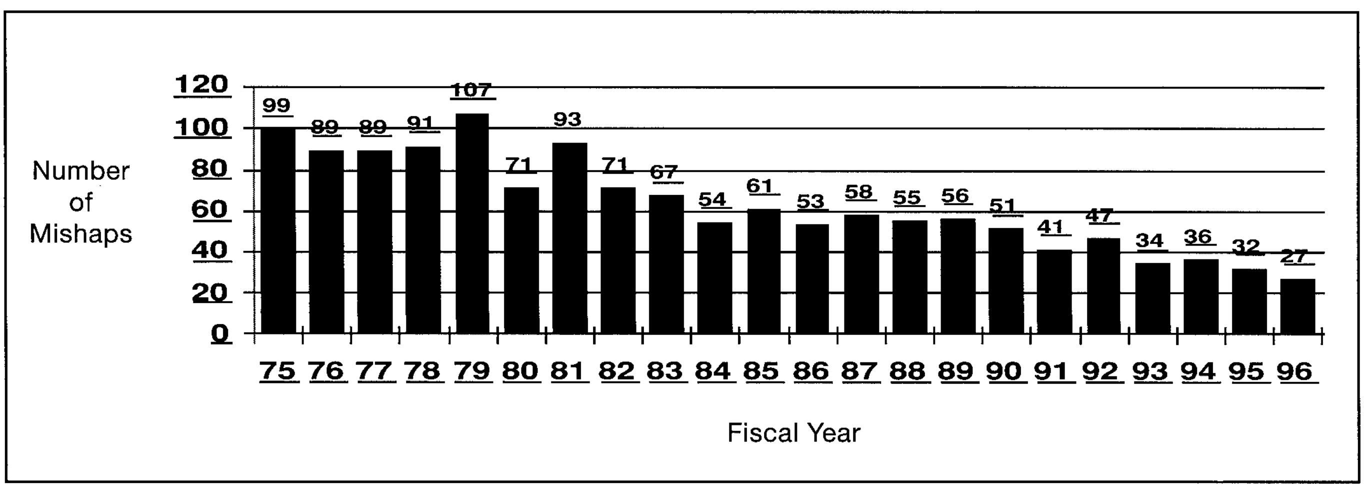


Figure 1. USAF Class A flight mishaps for government fiscal years 1975-1996.

Continued on page 14

Figure 2. Human factors experts, and other investigators, face a puzzle that may initially seem unsolvable.

consultants are not presently formal members of mishap boards. Instead, boards are primarily composed of aviators. Flight surgeons serve as the sole human factors expert on mishap boards and are simultaneously often dealing with the logistics of pathology of the victims (e.g., identifiying remains, preparing tissue samples for analysis, etc.) and their own reactions. They frequently consult human factors experts, either with a focused question, or request that a human factors expert (usually an active duty aerospace physiologist or clinical psychologist) join the Board for the entire duration of the investigation (approximately 30 days).

Human factors experts should not underestimate their usefulness as scientists. The SIB members are rated aviators and are thus prone to the same defenses as all aviators (more so in this threatening and stressful time). Human factors experts can teach them about the danger of drawing general conclusions from low base-rate events. In addition, pilots typically attribute an accident to the pilot as opposed to the aircraft. Human factors experts can help here by challenging the attributions that pilots may make regarding the nature of the accident.

The final product of the Board's labor is a 15,000 to 20,000 word document, compiled by a group of former strangers during an average of thirty days of intensive work. The document is then briefed to the convening authority (typically a four-star general); the Chief of Staff of the Air Force and the Secretary of the Air Force may also be briefed.

The report details what happened, how it happened, and why it happened, with recommendations to avoid reoccurrence. The research and development community may become involved with the remedy of design, procedural, and training deficiencies. While the entire report is not releasable, information may be "sanitized" (i.e., removing identifying and incriminating information) and briefed to aviators and other personnel in the aviation community to provide lessons learned to avoid reoccurrence, proving that those who learn from history are not condemned to repeat it! ●

Copies of the report *A Human Factors Guide for Consultants to USAF Aircraft Mishap Investigations* are available through:

Defense Technical Information Center (DTIC-BR)
8725 John J. Kingman Road
Suite 0944
Ft Belvoir VA 22060-6218

Acknowledgment

I would like to gratefully acknowledge the continuing support of Lt Col (Sel) Joyce A. Adkins, AF Safety Center, Kirtland AFB, NM.

Major Raymond E. King, PsyD., is a licensed psychologist and Chief of the Collaborative Systems Technology Branch, Fitts Human Engineering Division, Crew Systems Directorate, Armstong Laboratory, Wright-Patterson AFB, OH. He recently served as a human factors consultant to the C-130 Presidential Support mission that crashed in Jackson Hole, WY, and as the senior human factors consultant to the Secretary of the Air Force-directed reinvestigation (Accident Investigation Board) of the Pope AFB NC F-16/C-130 midair collision.

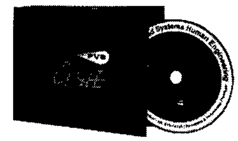
Questions? Comments? Address Change?

Please contact the Editor, Jeff Landis, at:

CSERIAC Program Office
AL/CFH/CSERIAC Bldg 248
2255 H Street
Wright-Patterson AFB OH
45433-7022 USA

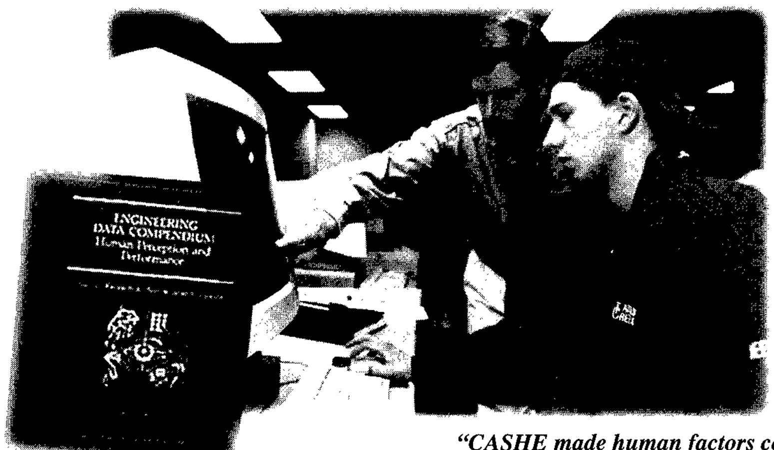
Tel: 937-255-4099 or 4842
Fax: 937-255-4823
Email: landis@cpo.al.wpafb.af.mil

YOUR HUMAN FACTORS Teaching TOOL for the CLASSROOM on CD-ROM



CASHE : PVS

(Computer Aided Systems Human Engineering Performance Visualization System)

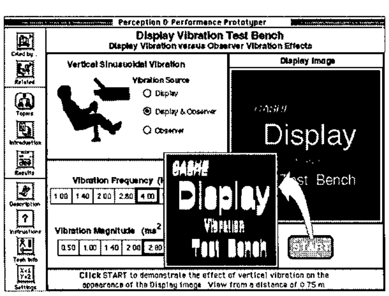


"CASHE made human factors concepts come to 'life' when the book just couldn't do it."
Capt Terence Andre-Assistant Professor of Behavioral Sciences, USAF Academy

CASHE *enhances* your understanding of human factors by combining text, graphics, sound, and animation. With **CASHE**, you can *manipulate* human performance variables, such as vibration, using the built-in *test benches*. **CASHE** has 11 of these test benches to enhance your understanding of human factors involving motion, sound, speech, and vision.

Human Performance data is easily *accessible* with **CASHE**. You get complete, *hyperlinked* electronic versions of the Engineering Data Compendium, MIL-STD-1472D, and the eleven Perception and Performance test benches on CD-ROM.

Now, it's all in one place. And it's available to you.



Sample screen from the Display Vibration Test Bench. This test bench allows manipulation of vibration frequency and magnitude, as well as vibration source, vibration axis, vibration waveform, and type of display. You can then view a display that simulates how these vibration conditions affect the legibility of the display. Other test benches include Auditory Sensitivity, Flicker Sensitivity, Manual Control, Motion Perception, Sound Localization, Speech Intelligibility, Visual Acuity, Visual Optics, Visual Search, and Warnings and Alerts.

Call 937/255-3880 to order

*System requirements: **CASHE** is designed to operate on the Macintosh®.*

CSERIAC
ARMY NAVY AIR FORCE NASA FAA NATO

Crew System Ergonomics Information Analysis Center is sponsored by the Department of Defense, Defense Technical Information Center (DTIC), technically managed by the Armstrong Laboratory Human Engineering Division, and operated by the University of Dayton Research Institute.

ARMY NAVY AIR FORCE NASA FAA NATO

NEWS FROM the

CREW SYSTEM ERGONOMICS INFORMATION ANALYSIS CENTER:

- SHOULD AN INTERFACE ALWAYS MATCH THE OPERATOR'S MENTAL MODEL?
- CALENDAR
- THE CSERIAC INTERFACE
- DEAR CSERIAC
- INFORMATION VISUALIZATION AND INFORMATION FORAGING
- A CONVERSATION WITH STUART CARD
- AIRCRAFT MISHAP INVESTIGATION: A ROLE FOR HUMAN FACTORS CONSULTANTS
- CSERIAC PRODUCTS AND SERVICES

Bulk Rate
US Postage Paid
Dayton Ohio
Permit No. 71

CSERIAC • UNIVERSITY OF DAYTON • 300 COLLEGE PARK • DAYTON • OHIO 45469-0157

CSERIAC PRODUCTS AND SERVICES

CSERIAC's objective is to acquire, analyze, and disseminate timely information on crew system ergonomics (CSE). The domain of CSE includes scientific and technical knowledge and data concerning human characteristics, abilities, limitations, physiological needs, performance, body dimensions, biomechanical dynamics, strength, and tolerances. It also encompasses engineering and design data concerning equipment intended to be used, operated, or controlled by crew members.

CSERIAC's principal products and services include:

- technical advice and assistance;
- customized responses to bibliographic inquiries;
- written reviews and analyses in the form of state-of-the-art reports and technology assessments;
- reference resources such as handbooks and data books.

Within its established scope, CSERIAC also:

- organizes and conducts workshops, conferences, symposia, and short courses;
- manages the transfer of technological products between developers and users;
- performs special studies or tasks.

Services are provided on a cost-recovery basis. An initial inquiry to determine available data can be accommodated at no charge. Special tasks require approval by the Government Technical Manager.

To obtain further information or request services, contact:

CSERIAC Program Office
AL/CFH/CSERIAC Bldg 248
2255 H Street
Wright-Patterson AFB OH 45433-7022

http://www.udayton.cseriac.edu

Telephone .... (937) 255-4842
DSN 785-4842
Facsimile .... (937) 255-4823
Gov Tech Manager .... (937) 255-2558

Director: Mr. Don A. Dreesbach; *Government Technical Manager:* Dr. Joe McDaniel; *Associate Government Technical Manager:* Ms. Tanya Ellifritt; *Government Technical Director:* Dr. Kenneth R. Boff.

CSERIAC Gateway is published and distributed free of charge by the Crew System Ergonomics Information Analysis Center (CSERIAC). *Editor:* Jeffrey A. Landis; *Copy Editor:* R. Anita Cochran; *Layout Artist:* Allison L. Herron.